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PEOPLE'S REPUBLIC OF CHINA LASER RADIATION SAFETY STANDARD

by

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PEOPLES REPUBLIC OF CHINA LASER RADIATION SAFETY STANDARD

Jian Yigao

(Suggested Draft)

Cooperative Research Team of the National Scientific and Technical Commission on Laser Safety Protective Standards

Abstract, The recommended draft of Safety Standard of Laser Radiation is compiled by the National Colloborated Group of Laser Safety and Protection Research, organized by the National Scientific and Technical Commission. Keywords: Laser safety standards; Laser hazards; Thresholds (Physiology), Chinese translations. (edc)

In September of 1980, the National Scientific and Technical Commision organized the concerned specialists and carried out discussions on the research problems of laser light protective standards. The participants, on the basis of the practical applications of lasers over the last 20 years, definitely established that lasers do do damage to the human body and, in particular, to the eyes and skin. For many years, the several score of acute eye injury cases which have occurred clearly show this. Lasers, even if they are reflected or diffused, are all capable of damaging the eyes. The meeting recognized that this research needed to be carried out as quickly as possible. After the meeting, the commision set up the All China Laser Safety Protective Standard Research Cooperative Team.

This cooperative team was principally formed from the Shanghai No.2 Medical College, the China Military Medical Science Academy, the Shanghai Medical University, The Guangzhou Zhongshan Medical Academy, the Xian Medical Academy, the China Measurement Science Research Academy, the Tianjin City Laser Research Institute, the Tianjin Labor Health Research Institute, the Tianjin City Opthalmic Science Academy, and other similar units. The participating scientific research and medical personnel reached more than 80 persons. The cooperative team, went through large amounts of testing, research and investigative analysis and handled the translation of advanced international laser safety standards. On this basis, the team wrote these standards, which have already been reported to the relevant agencies for approval.

1. SCOPE OF APPLICABILITY

1.1 Object: the specification of these standards which should be carried out by all units having laser devices (wavelengths in the range of 200nm-1mm).

1.2 Application: These standards offer appropriate guidance for the safe use of laser devices and laser device systems. On the basis of the capability for biological damage caused to the eyes and skin by laser light bundles or sheafs and their reflected bundles, it is possible to take laser devices and divide them into 4 types. Each type had appropriate control measures.

Each unit should appoint laser operator personnel with abundant experience or who have gone through specialized training to take on the duties of laser safety personnel. The duties of these personnel are to carry out a classification of the regulations from the second and sixth sections as they apply to all the laser devices and laser device systems which the units concerned have. After that, according to the requirements of sections No.3, No.4, and No.5, they synthesize the actual status of the unit, set up effective protective measures and oversee the administration of the rules.

2. STANDARDS CLASSIFYING LASER DEVICES AND LASER DEVICE SYSTEMS ACCORDING TO THEIR DEGREE OF HARMFULNESS

2.1 Laser devices and laser device systems can be classified into four types on the basis of their degree of harmfulness.

2.1.1 No.1 Type laser devices and laser device systems--Under normal operational conditions, the laser light radiated does not produce any harm, and it is possible to exempt them from control measures.

2.1.2 No.2 Type laser devices and laser device systems--Belonging to the low power range, in the visible light band (400nm-700nm), their continuous radiation levels are larger than those of the No.1 Type laser devices. However, they do not exceed 1mw (radiation time is greater than 0.25 sec). When the laser devices adopt the pulse mode of radiation, the radiation levels are not able to exceed 0.1 μJ. If one stares for long periods at this type of visible wave band laser light, it is possible to cause retinal damage. 2
Because of this, it is necessary to adopt appropriate control measures.

2.1.3 No.3 Type laser devices and laser device systems--Belonging to the middle power range, this type of laser device has radiation levels larger than those of the No.1 and No.2 Types. The human body (in particular, the eyes) receiving direct radiation for a short period from this type of laser device, is able to give rise to biological damage. Because of this, control measures for this type of laser device are indispensible. However, their diffused or reflected laser light bundles are not harmful.

2.1.4. No.4 Type laser devices and laser device systems--Belonging to the high power range, their radiation levels exceed those of the No.3 Type. They are capable of producing dangerous direct laser light bundle radiation and diffused and reflected radiated light bundles. The human body (in particular, the eyes), when in receipt of this type of direct laser light for short periods or of diffused irradiation, is capable in all cases of giving rise to biological damage. Because of this, it is necessary to adopt severe control measures.

2.2 The various types of laser devices and laser device systems all should be classified on the basis of the maximum radiation levels which they are capable of reaching. The various types of laser devices have radiation levels which can be seen in Tables 1 and 2. The standards in question handle radiation durations larger than or equal to 0.25 seconds with the laser devices specified as continuous laser devices and smaller than 0.25 second laser devices specified as pulse type laser devices.

2.3 As far as the repeated pulse (exceeding 1Hz) class of laser devices is concerned, it is possible, on the basis of their overall pulse operational period (the number of pulses multiplied by the width of a single pulse) to put standards into effect corresponding to the classes of continuous or single pulse laser devices.

3. STANDARDS FOR THE RECEIVING OF LASER LIGHT RADIATION BY EYES AND SKIN

3.1 Laser damage to the eyes. The acuteness of the effects of laser light irradiation on eyes varies with the wavelength. And, it is possible for this to become corneal and retinal burning. As far as the chronic effects of laser irradiation of the eyes is concerned, it is possible for this to be corneal or lens clouding or turbidity or retinal damage.

1 表 1　连续波激光器发射水平分级标准

2 波长范围(nm)	发射时间 3 (s)	I 级 4	II 4 级	III 4 级	IV 4 级
5 紫外(200—400)	3×10^4	$\leqslant0.8\times10^{-9}$w—$\leqslant8\times10^{-6}$w 6 取决于波长	—	>I 级但≤0.5 w 7 取决于波长	>0.5 w
8 可见(400—550)	3×10^4	$\leqslant0.4\times10^{-6}$w	>I 级, 9 但≤1mw	>II 级 10 但≤0.5 w	>0.5 w
11 可见和近红外 (550—1060)	3×10^4	$\leqslant0.4\times10^{-6}$w—$\leqslant200\times10^{-6}$w 12 取决于波长	—	>I 级但≤0.5 w 13 取决于波长	>0.5 w
14 近红外(1060—1400)	3×10^4	$\leqslant200\times10^{-6}$w	—	>I 15 级但≤0.5 w	>0.5 w
16 远红外(1400—10^3)	>10	$\leqslant0.8\times10^{-3}$w	—	>I 级但 17 ≤0.5 w	>0.5 w
18 亚毫米(10^2—10^3)	>10	≤0.1 w	—	>I 级但 19 ≤0.5 w	>0.5 w

1. Table 1 Standards for the Classification of the Radiation Levels of Continuous Wave Laser Light Devices 2. Wavelength Range 3. Radiation Time 4. Class 5. Ultraviolet 6. Determined by Wavelength 7. Greater Than Class I But Less Than or Equal to 0.5W Determined by Wavelength 8. Visible 9. Greater Than Class I But Less Than or Equal to 1MW 10. Greater Than Class II But Less Than or Equal to 0.5W 11. Visible and Near Infrared 12. Determined by Wavelength 13. Greater Than Class I But Less Than or Equal to 0.5W Determined by Wavelength 14. Near Infrared 15. Greater Than Class I But Less Than or Equal to 0.5W 16. Far Infrared 17. Greater Than Class I But Less Than or Equal to 0.5W 18. Submillimeter 19. Greater Than Class I But Less Than or Equal to 0.5W

1 表 2　单脉冲激光器发射水平分级标准

2 波长范围 (nm)	发射时间(s) 3	I 级 4	III 级 4	IV 级 4
5 紫外200—400	$>10^{-2}$	$\leqq24\times10^{-6}$J—7.9×10^{-3}J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
7 可 见	10^{-9}	$\leqq0.2\times10^{-6}$J	>I 级 6 但$\leqq31\times10^{-3}$J·cm^{-2}	$>31\times10^{-3}$J·cm^{-2}
400—700	— 0.25	$\leqq0.25\times10^{-3}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
8 近 红 外	10^{-9}	$\leqq0.2\times10^{-6}-2\times10^{-6}$J	>I 级 6 但$\leqq31\times10^{-3}$J·cm^{-2}	$>31\times10^{-3}$J·cm^{-2}
700—1060	— 0.25	$\leqq0.25\times10^{-3}-1.25\times10^{-3}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
1060—1400	10^{-9}	$\leqq2\times10^{-6}$J	>I 级 6 但$\leqq31\times10^{-3}$J·cm^{-2}	$>31\times10^{-3}$J·cm^{-2}
	— 0.25	$\leqq1.25\times10^{-3}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
9 远 红 外	10^{-9}	$\leqq80\times10^{-6}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
1400—10^4	— 0.25	$\leqq3.2\times10^{-3}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
10 亚 毫 米	10^{-9}	$\leqq10\times10^{-3}$J	>I 级 6 但$\leqq10$J·cm^{-2}	>10J·cm^{-2}
10^4—10^5	— 0.25	$\leqq0.4$J	>I 级 6 但$\leqq10$J·cm^2	>10J·cm^{-2}

1. Table 2 Standards for the Classification of Single Pulse Laser Light Devices by Radiation Level 2. Wavelength Range 3. Radiation Time 4. Class 5. Ultraviolet 6. Class But 7. Visible 8. Near Infrared 9. Far Infrared 10. Submillimeter

1 表 3　直视激光束的角膜最大容许照射量(或曝光限)

3 波长λ(nm) \ 照射时间t(s) 2	≤10^{-9}	10^{-9}—10^{-7}	10^{-7}—18×10^{-6}	18×10^{-6}—50×10^{-6}	50×10^{-6}—10	10—10^3	10^3—10^4	10^4—3×10^4
200—302.5	3×10^6w/cm²	3 mJ/cm²						
302.5—315	3×10^6w/cm²	$t>T_1$　$C_1\times10^{-1}$ mJ/cm²; $t<T_1$　$0.56\,t^{1/4}$ J/cm²					$C_1\times10^{-1}$ μw/cm²	
315—400	3×10^6w/cm²	$0.56t^{1/4}$ J/cm²				1J/cm²	1 mw/cm²	
400—550	5×10^2w/cm²	5×10^{-7} J/cm²		$t<T_2$　$1.8t^{3/4}$ mJ/cm²		1×10^{-2}J/cm²		1μw/cm²
550—700	5×10^2w/cm²	5×10^{-7} J/cm²		$t<T_2$　$1.8t^{3/4}$ mJ/cm²		$t>T_2$ $10C_2$ mJ/cm²		C_2μw/cm²
700—1050	$5C_3\times10^2$ w/cm²	$5C_3\times10^{-7}$J/cm²		$1.8C_3t^{3/4}$ mJ/cm²			$320C_3$ μw/cm²	
1050—1400	5×10^3w/cm²	5×10^{-6} J/cm²			$9t^{3/4}$ mJ/cm²		1.6 mw/cm²	
1400—10^6	10^7w/cm²	10mJ/cm²	$0.56t^{1/4}$ J/cm²			10^{-1} w/cm²		

4 注：$T_1=10^{0.8(\lambda-295)}\times10^{-15}$，$C_1=10^{0.2(\lambda-295)}$，$T_2=10\times10^{0.02(\lambda-550)}$，$C_2=10^{0.015(\lambda-550)}$，
$C_3=10^{[(\lambda-700)/500]}$

1. Table 3 Maximum Permissible Doses of Corneal Radiation for Direct Observation of Laser Light Bundles (Or Light Exposure Limits) 2. Radiation Time 3. Wavelength 4. Note

1 表 4　观察扩展源漫射光束时，角膜的最大容许照射量(或曝光限)

3 波长λ(nm) \ 照射时间t(s) 2	≤10^{-9}	10^{-9}—10^{-7}	10^{-7}—10	10—10^3	10^3—10^4	10^4—3×10^4
200—400	4 同 表 3					
400—550	10^7w/cm²·sr	$10t^{1/3}$ J/cm²·sr		21 J/cm²·sr		2.1 mw/cm²sr
550—700	10^7w/cm²·sr	$10t^{1/3}$ J/cm²·sr		$t<T_2$ $21C_2$ J/cm²·sr; $t>T_2$ $3.8t^{3/4}$ J/cm²·sr		$2.1C_2$ mw/cm²·sr
700—1400	10^7C_3 w/cm²·sr	$10C_3t^{1/3}$ J/cm²·sr		$3.8C_3t^{3/4}$ J/cm²·sr	$0.64C_3$ w/cm²·sr	
1400—10^6	4 同 表 3					

1. Table 4 Maximum Permissible Amounts of Corneal Radiation (or Light Exposure Limits) When Observing Expanded Source Diffused Light Radiation Bundles 2. Radiation Time 3. Wavelength 4. Same as Table 3

1 表 5 激光辐照皮肤的最大容许照射量(或曝光限)

照射时间t(s) 2 / 波长λ(nm) 3	≤10^{-9}	10^{-9}—10^{-7}	10^{-7}—10	10—10^{3}	10^{3}—3×10^{4}
200—400	4 同表 3				
400—1400	2×10^{7}w/cm²	20mJ/cm²	$1.1t^{1/4}$J/cm²	0.2 w/cm²	
1400—10^{6}	4 同表 3				

1. Table 5 Maximum Permissible Doses of Radiation (or Light Exposure Limits) for Laser Light Irradiation of the Skin 2. Radiation Time 3. Wavelength 4. Same as Table 3

3.2 Harm to the skin from laser light. Acute effects from high 4
strength laser light irradiation of the skin is capable of causing the appearance of red striations or faculae in the skin even up to the point of burns. Certain specific types of ultraviolet laser light are capable of having cancer causing effects.

3.3 Maximum permissible doses of laser light radiation received by the eyes and skin (MPE). (See Tables 3, 4, and 5) Their values are below the harmful levels.

The methods used for measuring the MPE for the various types of laser devices and laser device systems can be seen in Section 6.

3.4 Definitions concerning the internal view of light bundles and the viewing of expanded or diffused sources. These standards specified the eye MPE for the viewing of the interior of light bundles and the MPE for expanded or diffused sources. The definitions for the internal viewing of light bundles and the viewing of expanded sources (See Fig. 1-3) are given below.

On the basis of the size of the observation angle (α), in Fig.3, when its size is smaller than the α_{min} value in Table 6, this is recognized as interior viewing of light bundles (the point of direct observation is the light source, as shown in Fig.1 and Fig.2). If a is equal to or larger than α_{min} then this is the observation of an expanded or diffused source. For different radiaion conditions, α_{min} is different.

1 表 6　两个波段的极限表观视角值

照射时间 2 (秒)	3 极限表观视角(毫弧度)	
	$\lambda=400—1050nm$	$\lambda=1051—1400nm$
10^{-9}	8.0	11.3
10^{-8}	5.4	7.7
10^{-7}	3.7	5.4
10^{-6}	2.5	3.7
10^{-5}	1.7	2.5
10^{-4}	2.2	—
10^{-3}	3.6	—
10^{-2}	5.7	—
10^{-1}	9.2	—
1	15	—
10	24	—

1. Table 6 Surface Observation Angle Value Limits for Two Wave Bands 2. Radiation Time 3. Surface Observation Angle Limits (Millidegrees of Arc)

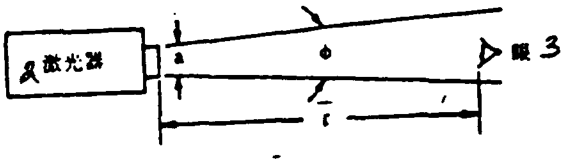
3.5 Multiple pulse line, scanning lasers or infrared wave band MPE's require the carrying out of calculations on the basis of the frequency of repetition of the pulses and the light spectrum absorption correction or calibration factor.

4. LASER PROTECTIVE SAFETY MEASURES AND SAFE OPERATING REGULATIONS

4.1 Laser instrument production and test manufacture units should adopt the following measures.

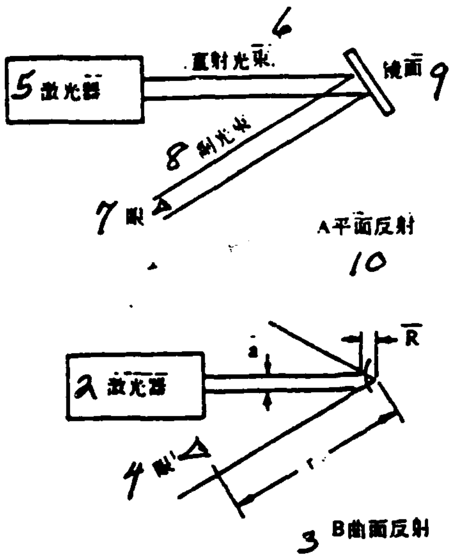
4.1.1 An explanation of the parameters required for the laser safety protective measures presented here includes the wavelength range, maximum output power, and the total power (or peak value power) for each pulse from pulse lasers. This also includes pulse width and pulse repetition frequency.

4.1.2 According to the standards in Section 2, on the basis of 5
the operational characteristics of lasers, one can clarify which class they belong to.



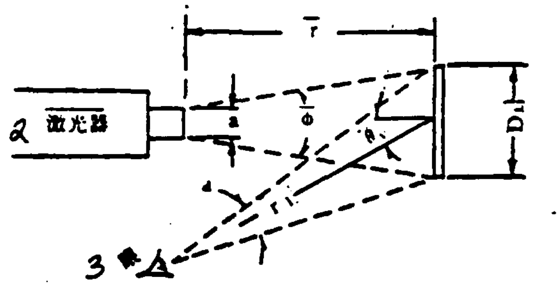
1 图 1 光束内观察——直射(主)光束

1. Fig.1 Light Bundle Interior Observation--Direct Radiation (Main) Light Bundle 2. Laser Device 3. Eye



1 图 2 光束内观察——镜面反射(副)光束
A. 平面反射 B. 曲面反射

Fig.2 Light Bundle or Sheaf Interior Observation--Lens Surface Reflection (Secondary) Light Bundle A. Planar Reflection B. Curved Surface Reflection 2. Laser Device 3. B. Curved Surface Reflection 4. Eye 5. Laser 6. Direct Radiation Light Bundle 7. Eye 8. Secondary Light Bundle 9. Lens Surface 10. A. Planar Reflection



1 图 3 视扩展源——通常的漫反射光

4 图 1—3 中字母注释：
a 光束直径，ϕ 激光束发散角，
γ 激光出口至眼或漫反射物的距离，
γ_0 眼与镜面或曲面反射镜的距离，
R 曲面反射镜的曲率半径，γ_1 眼与漫反射物的距离，
D_L 漫反射物的大小，α 眼对漫反射物的表观视角，
θ_γ 激光主光束与漫射主光轴(眼与物中心连线)的夹角

1. Fig.3 Observing an Expanded or Dispersed Source--Ordinary Diffused Light Reflection 2. Laser Device 3. Eye 4. Explanation of the Letters Used in Fig. 1-3 a light bundle diameter, ϕ laser light bundle angle of divergence, γ the distance from the exit of the laser to the eye or to the diffuse reflecting object, γ_0 the distance from the eye to the lens surface or the curved reflecting lens surface, R the radius of curvature of the curved reflecting lens surface, γ_1' distance from the eye to the diffuse reflecting object, D_L the size of the diffuse reflecting object, α the angle of surface observation of the eye to the diffuse reflecting object, θ_γ the angle of separation between the main laser light bundle and the main light axis of diffusion (a continuous line from the center of the object to the eye)

4.1.3 When designing lasers, one should give sufficient consideration to the various types of safety measures.

4.1.3.1 Besides No.1 Type laser device systems, all equipment must be marked with safety warnings at clearly visible spots. The design for the markings is as shown in Fig.4. For the specifications of the markings, see the table appended to Fig.4.

4.1.3.2 Laser devices and laser device systems should have sealed covers, key control switches, as well as equipment to warn when the systems are on, and so on. This is particularly true of No.3 and No.4 Type laser devices.

4.1.3.3 The terminal ends of the light bundles of No.3 and No.4 Type laser devices require the installation of high absorbancy or non-combustible materials. As far as non-visible infrared rays or ultraviolet ray laser devices are concerned, even more care should be taken. Their light bundle terminals require covers.

4.1.3.4 If at all possible, laser devices and laser device systems are best started by remote control and run under supervision.

4.2 Control Measures for the Environment of Laser Device Installation

4.2.1 All units which have laser devices (wavelengths from 200nm-1mm) should install the various types of laser devices in different rooms in order to simplify the safety operating regulations.

4.2.2 In laser laboratories and treatment rooms, the illumination must be adequate in order to reduce the amount of luminous flux entering the interior of the eye. The walls and ceilings should use light colored non-glossy paint in order to reduce as much as possible any mirror type reflecting surfaces. Glass windows should use frosted glass. Metal door handles and treatment machinery is best painted. The surrounding environment must have striking "Laser Danger" signs in order to cause the personnel concerned to be careful. When laser devices are operating, room doors should have warning indicator lights.

4.2.3 If No.3 and No.4 Type laser devices do not have sealed covers, use should be made of covering or shielding materials that do not transmit laser light to block the laser light bundle in order to keep it from reaching the area containing personnel.

4.2.4 In places where laser devices are operated, easily combustible, easily explosive items must be kept away from the lasers (this is particularly true of No.4 Type) in order to prevent the laser bundle from causing other unexpected accidents.

4.2.5 When lasers are fired over long distances outside the laboratory, one should consider the angle of divergence of the laser light bundle, the output energy, the diameter of the light bundle, the atmospheric attenuation parameter and other similar factors. When the operational distance is shortened to a safe one, it is necessary to shield the light path with strict security.

4.3 Operating regulations for laser operator personnel and assistants

4.3.1 In environments with lasers operating, the operator personnel should all receive laser safety education and training to give them an awareness and respect for safety operating procedures.

4.3.2 One cannot look directly at laser light bundles. Operator personnel who come in contact with No.3 and No.4 Type laser devices must wear laser protective glasses which correspond to the wave band of the laser before they operate the device. Even when they do wear the protective glasses, it is still not possible to look directly into the main light bundle. Much less is it possible to use optical instruments to observe the laser light bundles. If one uses a microscope to observe an object that has been irradiated by the laser bundle, it is necessary to adopt for use appropriate filtering devices in order to weaken the laser light entering the human eye to safe levels.

4.3.3 Before turning on laser devices and laser device systems, one must take bodies with mirror type reflecting surfaces out of the laser area.

4.3.4 When one stops making use of laser light, one should, as quickly as possible, cut off the light path or the switch of the light source. Keys should be taken out of locking type switches.

4.3.5 Laser operator personnel, when operating laser devices, must also strictly maintain control of the relevant electrical operating systems in order to prevent high voltage electrical contacts and other similar accidents.

4.3.6 Assisting personnel or observers should not take it upon themselves to turn the laser devices on. If possible, when laser devices are operating, it is best to leave the area of laser operation.

4.3.7 In medical applications, operator personnel must, as quickly as possible, take care of the contaminants from tissue vaporized by lasers, strengthening the operating room ventilation. During operations, it is possible to use wet bandages or inject biological saline solution or use other similar methods in order to give patients protection. The patients eyes must be covered. In operations where it is necessary to use oxygen, one must be careful to prevent the lasers from causing fires.

4.3.8 When laser devices and laser device systems must be checked and maintained, or replaced, the operator personnel concerned must pay attention to dropping the laser output level down to MPE and only then operating it.

4.4 Laser operator personnel and assistants are capable of running into other dangerous factors (poisonous substances, noise, high voltage electricity, ionization radiations, and so on), and all of these are handled in accordance with the corresponding health standards and protective regulations.

5. MEDICAL SUPERVISION

Due to the fact that direct laser irradiation or indirect radiation through other reflecting objects onto human eyes or skin (especially with the No.3 and No.4 Type laser devices) is capable of causing danger, in order to prevent personnel receiving harmful radiation as well as insuring the quick adoption of appropriate treatment measures, medical supervision is absolutely necessary.

5.1 Physical Examination Requirements

6

5.1.1 In various areas, it is necessary to point out the physiological investigations carried out by specialized medical treatment organizations on all the laser operating personnel in these districts. The responsibility of the aforementioned medical organizations was to investigate materials concerning acute and chronic damage to the human body by accumulations of laser light and to set up files of these physical examinations in order to lay a foundation for the development of epidemiological research on the dangers of laser light.

5.1.2 The various units just took part in the appropriate examinations carried out by the medical organizations indicated as a necessary beginning in studying the laser workers (the eyes and skin were studied in particular). The best period for the physical examinations was once a year.

5.2 Accident reports. Laser safety personnel in the various units have the responsibility to record the circumstances surrounding the occurrance of accidents as well as reporting these accidents to the indicated medical treatment organizations.

6. METHODS FOR THE MEASUREMENT OF RATINGS AND MPE EVALUATIONS FOR LASERS AND LASER SYSTEMS

6.1 General: The measurement of ratings and MPE evaluations for lasers and laser systems must follow the principles set out below.

6.1.1 Lasers must be adjusted to maximum output levels, eliminating the random scattering of light in wavelengths being measured. Measurements must be carried out with lasers in their normal operational configurations.

6.1.2 When the light strength distribution in bundle cross sections is not uniform, the ratings and evaluations should be carried out using the strongest areas as the basis.

6.1.3 When doing ratings on continuous laser devices, one should measure the overall power of light bundles. The receiving area for figuring the power should be larger than the diameter of the light bundle. If it is smaller than the diameter of the light bundle, one should do a complete calibration of the light bundle.

6.1.4 When doing ratings on Class 3 and 4 pulse laser devices,

one should use a round aperture of diameter 1mm to measure its degree of maximum output radiation or amount of radiation.

6.1.5 When doing evaluations of the maximum permissible doses of radiation (MPE) on laser devices and laser device systems as well as the interior of their light bundles, one should take the receptor head of the laser light measuring device and place it in the middle of the light bundle. When doing MPE evaluations of diffused light, one should place the receptor head in the personnel work area in order to make the maximum radiation dose (or radiation degree) in this area standard.

6.1.6 Test personnel should become familiar with laser technology and relevant testing methods.

6.2 Limit aperture diameters. When measuring and calculating MPE, it is necessary to make use of appropriate aperture diameters. These standards refer to these as limit aperture diameters. They are the diameters of the largest circular areas for selected average values of radiation amounts and degrees of radiation.

6.2.1 When evaluating MPE for the skin, the measurements' limit aperture diameter is 1mm.

6.2.2 When evaluating MPE for the eyes, for wavelengths of 200-400mm and 1.4-1000 μm, the limit aperture diameter is 1mm. When the wavelength is 400-1400nm, it is 7mm.

6.3 Instruments

6.3.1 When using a 1mm limit aperture diameter to measure light bundles, the laser light measuring meter receptor head should have a degree of surface acuity which is uniform everywhere.

6.3.2 Measuring instruments should all be checked through the national measures department, and the total measurement error should not exceed $\pm 20\%$.

Note: These standards also contain an explanation of terms, requirements for the manufacture of safety glasses, an explanation of warning signs, maximum permissible doses of radiation, actual calculations for the classification of laser devices, and several other similar appendices. These have been deleted.

A REVIEW OF STUDIES ON LASER SAFETY AND PROTECTIVE STANDARDS
AN EXPLANATION OF THE DRAFTING OF THE "PEOPLES REPUBLIC OF CHINA LASER RADIATION SAFETY STANDARD"

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Abstract, This paper reviews the recent development of laser safety studies in China. Based on the analysis and comparison of the biological data in china and abroad, and in terms of international advanced laser safety standards, some essential factors are briefly discussed for sctting the Chinese Safety Standard of Laser Radiation.

SUMMARY: This work summarizes the results of experimental research carried out over the last few years by the National Scientific Laser Safety Protective Standard Cooperative Research Team. It explains, on the basis of an analysis and comparison of corresponding biological data from inside and outside China, and a consulting of advanced international standards, the prinicpal basis for the standard which our country has set up.

Laser technology, in the various domains of our country's industry, agriculture, medicine, science, technology, and national defense, is daily gaining wider applications. Laser workers and personnel in contact with lasers are rapidly increasing in number. In order to practically carry out the guidance to "put prevention first" and "protect the environment and bring happiness to the people", the question of laser safety protection has already been put on the agenda.

On the basis of overseas science and technology reports, all the developed countries have already organized their specialist capabilities in order to handle research into laser safety protective standards and the work of setting them down in final form. Moreover, along with the development of laser technology and a deep commitment to relevant research, many revisions have been made to laser safety protective standards. At the present time, the nations which have standards or regulations are the U.S., U.K., West Germany, U.S.S.R., Canada, Sweden, France, Denmark, Austria, and others. Among them, we have already collected materials from the majority. Besides this, we are in possession of information that Japan is also in the midst of increasing the importance of this item of research. China, in the area of the application of lasers, is also one of the nations which began its development relatively early. This was done because a great power cannot be without its own laser safety standards, appropriate to the biological peculiarities of oriental people.

The All China Laser Protective Standard Research Cooperative Team organized by the National Science and Technology Commission carried out over three years experimental research from 1982 to 1985. On the basis of foreign experience in research on laser protective standards and investigations into the status of domestic use of laser devices, the cooperative team used eight types of common laser devices (11 types of wavelengths) to make experiments on the damage thresholds for eyes and skin.

1 表 1 激光对眼的损伤阈(ED_{50})

2 波长(nm)	3 实验对象	4 照射时间(s)	角膜上光斑直径 5 (mm)	6 角膜上入射的能量密度或功率密度(J/cm^2或w/cm^2)	7 备注
222	兔 11 眼	8×10^{-9}	1	54.4×10^{-3} J/cm^2	对角膜的损伤 8
308	兔 11 眼	$8-10\times10^{-9}$	1	0.83 J/cm^2	
488	兔 11 眼	1×10^{-1}	2.76	0.51 w/cm^2	对视网膜的损伤阈 9
488	兔 11 眼	1.45×10^{-1}	3	0.50 w/cm^2	
488	兔 11 眼	1	2.76	0.43 w/cm^2	
488	兔 11 眼	1	3	0.40 w/cm^2	
488	猴 12 眼	1×10^{-1}	2.76	0.834 w/cm^2	
488	猴 12 眼	1.45×10^{-1}	3	1.8 w/cm^2	
488	黄种人眼 13	1×10^{-1}	2.76	1.76 w/cm^2	
488	黄种人眼 13	1.45×10^{-1}	0.833	17.65 w/cm^2	
530	兔 11 眼	5×10^{-9}	5	39.2×10^{-6} J/cm^2	
530	兔 11 眼	8×10^{-9}	4	232.1×10^{-6} J/cm^2	
530	猴 12 眼	5×10^{-9}	5	187×10^{-6} J/cm^2	
632.8	兔 11 眼	1	4.3	178×10^{-3} w/cm^2	
632.8	兔 11 眼	1.25×10^{-1}	4.3	215×10^{-3} w/cm^2	
694.3	兔 11 眼	6×10^{-4}	5	14.9×10^{-3} J/cm^2	
694.3	兔 11 眼	7×10^{-4}	5	16.6×10^{-3} J/cm^2	
694.3	猴 12 眼	7×10^{-4}	5	42.5×10^{-3} J/cm^2	
1060	兔 11 眼	5×10^{-9}	5	1.2×10^{-3} J/cm^2	
1060	兔 11 眼	1.5×10^{-4}	1.5	97.6 w/cm^2	
1060	兔 11 眼	1.2×10^{-1}	5	5.4 w/cm^2	
1060	兔 11 眼	1.37×10^{-1}	1.7	67.2 w/cm^2	
1060	兔 11 眼	1	1.7	17.5 w/cm^2	
1060	兔 11 眼	1.02	5	2.5 w/cm^2	
1060	猴 12 眼	1.5×10^{-4}	1.5	333.3 w/cm^2	
1060	猴 12 眼	5×10^{-9}	5	4.3×10^{-3} J/cm^2	
1060	黄种人眼 13	1.5×10^{-4}	1.75	429 w/cm^2	
10600	兔 11 眼	1.2×10^{-1}	1	10.7 w/cm^2	对角膜的损伤 10
10600	兔 11 眼	1.25×10^{-1}	1	4.0 w/cm^2	
10600	兔 11 眼	1	1	3.6 w/cm^2	
10600	兔 11 眼	1.03	1	5.7 w/cm^2	

1. Table 1 Laser Damage Thresholds for Eyes (ED_{50}) 2. Wavelength 3. Test Object 4. Radiation Time 5. Corneal Faculae Diameter 6. Energy Density or Power Density Entering the Cornea 7. Remarks 8. Damage to the Cornea 9. Threshold of Retinal Damage 10. Corneal Damage 11. Rabbit Eye 12. Monkey Eye 13. Oriental Eye

Internationally, use has been made of probability and statistical methods of analysis in order to evaluate the laser damage thresholds. Generally, a damage threshold is defined as being the amount of laser radiation at which there is at least a 50% probability of the appearance of damage which is visible to the naked eye. As the damage thresholds for eyes and skin, we respectively took ED_{50} and MRD_{50} as representations. Due to the fact that the measurement of laser damage thresholds is a job of precise and detailed quantitative measurement, and, in order to guarantee that the results of the research would be reliable, the various units of the cooperative team established strict rules for experimental equipment in the areas of laser devices, optical systems, measurements of amounts of radiation, data handling as well as the indicators for biological observations, and other similar areas. (1) Laser radiation sources--Continuous outputs were all selected to be single type or mode devices. Pulse type output stabilities were smaller than $\pm 5\%$.

(2) Measuring devices used on radiation doses were all calibrated 9
through the National Measures Academy at regular intervals.

(3) In tests, the status of biological reactions was checked in all cases for histology either by optical microscope or by electron microscope.

(4) In data handling, we selected for use a reasonable weighted regression method for statistical processing, which was convenient to compare to the related material from overseas.

(5) Tests in each wave band were basically all carried out in each of two units respectively to facilitate investigations of the precision of the data.

As far as research on the laser light damage threshold for the eyes is concerned, the cooperative team selected for use eyes which were low in pigmentation and relatively close to man as found in the blue-green, purple, blue, and grey eyes of rabbits and monkeys, and these were used as the animal types. 8 wavelengths of laser light were used respectively. Irradiation was carried out over different radiation times. Respectively, the minimum radiation doses producing a 50% probability of damage (ED_{50}) which were obtained can be seen in Table 1.

1 表 2　激光对皮肤的损伤阈(MRD_{50})

2 激光波长 (nm)	3 实验对象	4 照射时间 (s)	MRD_{50}(J/cm²)	5 激光波长 (nm)	6 实验对象	7 照射时间 (s)	MRD_{50}(J/cm²)
10600	白 8 猪	1	3.7	694.3	白 8 猪	3.2×10^{-4}	53.3
10600	白 8 猪	1	2.4	694.3	黄种 9 人	3.2×10^{-4}	4.7
10600	黄种 9 人	1	2.7	514.5	黄种 9 人	1	7.1
10600	黄种 9 人	1	2.3	488	灰 10 猪	1	5.2
1060	白 8 猪	1	59.4	488	黄种 9 人	1	5.6
1060	白 8 猪	2×10^{-4}	4.6	488	黄种 9 人	1	5.6
1060	黄种 9 人	1	60.6	337.1	白 8 猪	4.5×10^{-9}	8.3
1060	黄种 9 人	1	71.4	308	白 8 猪	15×10^{-9}	53.8×10^{-3}
1060	黄种 9 人	2×10^{-4}	9.9	308	白 8 猪	$50-70\times10^{-9}$	73.0×10^{-3}
1060	黄种 9 人	3×10^{-4}	20.3	265	白 8 猪	9×10^{-9}	22.0×10^{-3}

11 注：光斑直径均为 5 mm。

1. Table 2 Laser Light Damage Thresholds for Skin (MRD_{50}) 2. Laser Light Wavelength 3. Test Object 4. Radiation Time 5. Laser Light Wavelength 6. Test Object 7. Radiation Time 8. White Pig 9. Oriental 10. Grey Pig 11. Note: The diameter of faculae were all 5mm.

As far as research on the laser light damage thresholds for skin is concerned, the cooperative team selected for use white pigs to be the animal type. 8 types of laser light wavelengths were used. Irradiation was carried out over different radiation times. Data, which was obtained, on the radiation dose data (MRD_{50}) for a 50% chance of the appearance of visible faculae in the skin can be seen in Table 2.

The results of the research discussed above offered a relatively comprehensive biological basis for the establishment of laser light safety protective standards for our country. In tests on the damage threshold for skin with 5 wavelengths of laser light, there were 120 volunteer tests of oriental people. The number of tests on human bodies exceeded the number reported for similar research outside of China. As far as measurements of the damage thresholds for the eyes from 222nm and 308nm ultraviolet laser light are concerned, as well as measurements of the thresholds for damage to the skin from 265nm

(quadruple frequency YAG lasers) and 308nm ultraviolet laser light, there are as yet no similar reports inside or outside China, and these data offered a definite basis for the establishment of ultraviolet laser light protective standards.

The damage thresholds for laser light on eyes and skin were the basis for the evaluation of the safe radiation levels for laser light. The All China Laser Light Protective Standard Cooperative Research Team carried out a detailed analysis of the totality of the research results. On the basis of the requirements of health statistical analysis, from probability equations, they derived the amounts of radiation (ED_{10} or MRD_{10}) which give rise to at least a 10% probability of damage. Moreover, they made a comparison to ED_{50} and MRD_{50}. $ED_{50}:ED_{10}=1.2-2.2:1$. $MRD_{50}:MRD_{10}=1.2-3.1:1$. The two specific values were both larger than 1. Because of this, when deriving maximum permissible radiation doses (MPE) or light exposure limits (EL) from ED_{50} or MRD_{50}, the safety factor can be taken to be between 5-20. Of course, when fiquring MPE from ED_{50}, due to the fact that the majority of materials are the results of experiments on animals, the safety factor can be somewhat bigger.

If one makes a comparison with the same sort of research outside of China, the Chinese skin MRD_{50} is basically located between the MRD_{50} for white people and the MRD_{50} for black people (see Table 3). Moreover, the ED_{50} for rabbit eyes or monkey eyes is slightly higher. However, the trends in changes with variations in radiation time are the same. This shows that the laser safety standards that we 10
have set up in China, refering to the international advanced safety protective standards, are well founded.

The cooperative team, in order to set up laser protective standards, not only completed the basic biological experiments discussed above. At the same time, they also gathered a large amount of material from inside and outside of China which relates to these matters. They handled the translation of the important international laser safety standards--the International Electrical Conference standards relating to laser product characteristics-the IEC, the World Health Organization's Environmental Health Standard 23, the American National Standards Institute Laser Device Safety Usage, ANSI Z136-1

1 表 3 中国人皮肤 MRD_{50} 与外国资料的比较

2 激光器	波长(nm) 3	4 照射时间(s)	实验(对象) 5	MRD_{50}(J/cm²)	EL(J/cm²)	MRD_{50}(下限)/EL 6
7 红宝石	694.3	2.5×10^{-3}	白 9 人	11—20	0.25	44
			黑 10 人	2.2—6.9		9
		0.32×10^{-3}	11 中国人	4.2—5.1	0.147	28
8 钕玻璃	1060	75×10^{-9}	白 9 人	4.2—5.7	0.1	42
			黑 10 人	2.5—3.0		25
		2×10^{-4}	中国人	9.3—10.6	0.65	14
		3×10^{-4}	中国 11 人	19.0—21.9	0.72	26
CO_2	10600	1.0	白 9 人	2.8	0.56	5
			黑 10 人	2.8		5
			中国 11 人	2.3—2.7		4
Nd:YAG	1060	1.0	白 9 人	48—78	5.5	9
			黑 10 人	46—60		8
			中国 11 人	60—71		11
Ar^+	488.0	1.0	白 9 人	4.0—8.2	1.1	4
			黑 10 人	4.5—6.0		4
			中国 11 人	5.6—5.64		5

1. Table 3 A Comparison of Chinese Skin MRD_{50} and Foreign Materials 2. Laser Device 3. Wavelength 4. Radiation Time 5. Test Object 6. Lower Limit 7. Red Ruby 8. Neodymium Glass 9. White People 10. Black People 11. Chinese People

1980, and so on. Besides these, there is also the investigation done by the authorities who handle laser operator personnel in such places as Beijing, Shanghai, Tianjin, Xian, Hebei, Dongbei, and so on, and the understandings they gained of the causes that give rise to acute laser incidents as well as the status of the physical exams of personnel in long term contact with lasers. Summarizing the experimental research, international materials and the status of investigative research in these three areas, the All China Laser Safety Standard Cooperative Research Team, on the basis of solicited suggestions from several score of laser production and research units throughout China, went through several revisions and set down this draft standard before you.

At the present time, our country has approximately three hundred or more units handling laser research and production. There are also quite a few laser medical treatment units. The operator personnel in contact with lasers exceed ten thousand. Because of this, setting up our country's laser safety protective standard and guaranteeing the safety of opertor personnel are important measures in the prospering of laser activities.

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